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Self-consistent kinetic approach to stratified regimes of a low-pressure spherical discharge

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A spherical glow discharge with a central point-like anode has been studied in self-consistent kinetic approach. The model includes non-local Boltzmann equation coupled with non-stationary ion balance equation, and Poisson equation for radial electric field. For low-pressure argon, the model permits to obtain moving striations in a spherical glow discharge.

1. Introduction

Spherical striations were observed in low-pressure glow discharge around point-like anode [1]. It was found that for different discharge conditions the radii of striations in a positive column of discharge obey relationship $r_{k+1}/r_k \approx$ const (geometric series) or $r_{k+1} - r_k \approx$ const (arithmetical progression). The reason for such different behavior of spherical striations is not clear yet. In [2], spherical striations were modeled in a given peak-like electric field. However, the solution of [2] was not self-consistent.

In the paper, this problem is studded on the basis of non-local Boltzmann equation for electron distribution function coupled with non-stationary balance equation for ions, and Poisson equation for self-consistent electric field.

2. Model

The model includes:

1. The non-local Boltzmann equation in two-term approximation for isotropic part of electron energy distribution function (EEDF) written in "total energy–space coordinate (radius from point-like anode)" representation:

$$\begin{aligned}&\frac{1}{r^2}\frac{\partial}{\partial r}\left[\frac{r^2U}{3H(U)}\frac{\partial}{\partial r}f_0(\varepsilon,r)\right]=\\&\frac{\partial}{\partial\varepsilon}\left[2\frac{m}{M}U^2N_gQ^d(U)f_0(\varepsilon,r)\right]+\\&\sum_k UN_gQ_k^{in}(U)f_0(\varepsilon,r)-\\&\sum_k (U+U_k^{in})N_gQ_k^{in}(U+U_k)f_0(\varepsilon+U_k^{in},r)\end{aligned} \tag{1}$$

where N_g is gas density, U is kinetic energy of electron, $\varepsilon=U-e_0\varphi(r)$ is total electron energy, $\varphi(r)$ is radial dependence of spherical discharge potential in the positive column (PC), $E(r)=-\partial\varphi/\partial r$ is electric field in the positive column of a spherical discharge. Eq. (1) is parabolic equations with source terms representing elastic, inelastic and ionizing electron-atom collisions.

2. The non-stationary continuity equation in drift approximation for ions

$$\frac{\partial n_i}{\partial t}+\frac{1}{r^2}\frac{\partial}{\partial r}(r^2n_i\mu_iE)=n_e\nu_I, \tag{2}$$

$\nu_I(r)$ is the direct ionization frequency, μ_i is ion mobility coefficient.

3. Poisson equation for self-consistent electric field:

$$\frac{1}{r^2}\frac{\partial(r^2E(r))}{\partial r}=4\pi e_0(n_i-n_e)\cdot \tag{3}$$

The solution of the system (1-3) was looked for in the region from the edge (r=R) of the positive column to the central anode with appropriate boundary conditions.

The iterative numerical procedure for the solution of the striation problem is used. At the first step, in order to obtain the first approximation of distribution function f_0^0(r,U), the parabolic equation (1) is solved in some proposed electric field E^0(r). From the f_0^0(r,U), the electron density distribution n_e^0(r) and the ionization frequency ν_I^0(r) are obtained. With the help of Eqs.(2-3), new approximation of electric field E(r) is found and the procedure is repeated until successive iterations of electric field are converged. Usually ten iterations are enough for the procedure convergence, and the final electric field distribution E(r) does not depend on the initial approximation of E_0(r). However, the voltage drop is kept constant.

3. Results

It was found that the iterative process is converging only in the case of moving striations. In spherical discharge, the solution for ion density and electric field are looked for in the form

$$n_i(t,r)=n_i^0\left(\frac{R}{r}\right)^{\beta}\bar{n}_i\left(\mathrm{v}_i^0t-\frac{R}{(3-\beta)}\left(\frac{r}{R}\right)^{3-\beta}\right) \tag{4}$$

$$E(t,r)=E^0\left(\frac{R}{r}\right)^{2-\beta}\bar{E}\left(\mathrm{v}_i^0t-\frac{R}{(3-\beta)}\left(\frac{r}{R}\right)^{3-\beta}\right) \tag{5}$$

where n^0_i and E^0 are characteristic values of ion density and electric field at r=R, $\bar{n}_i(t,r)$ and $\bar{E}(t,r)$ are dimensionless functions presenting waves moving with the phase velocity $\mathrm{v}_{st}=\mathrm{v}_i^0(r/R)^{2-\beta}$, the constant $\mathrm{v}^0_i=\alpha\mu_iE^0$ has the order of ion drift velocity. It should be noted that for $\alpha<0.25$ (standing striations corresponds to $\alpha=0$) the iterative process is not converged. Below all results are presented for $\alpha=0.5$. In the general case, parameter β can be in the range β=1-2. For β=2, average field and striation velocity v_{st} are constant. Ion and electron densities vary inversely proportional to the square of the distance r from the anode. Such dependencies were obtained in drift-diffusion approximation of a spherical glow discharge [3]. For $\beta=1$, the average electric field and densities n_i, n_e vary inversely proportional to r. In this case, the striation velocity decreases with the increase of the distance from the anode.

In Fig. 1, an example of self-consistent field distribution and electron density is presented for argon pressure p=0.5 Torr. It is seen that average electric field is modulated by several non-equidistant striation peaks.

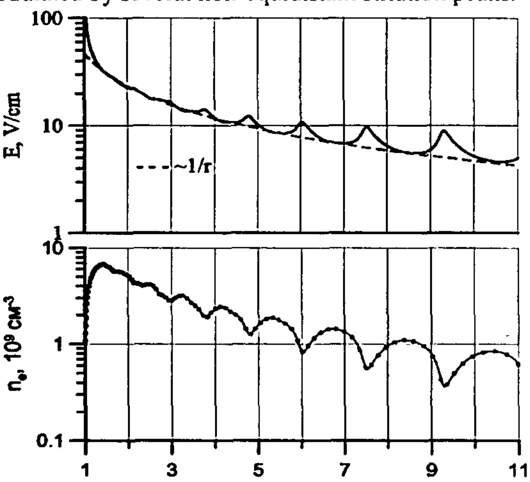

Fig.1. Electric field and electron density radial distributions in spherical striated glow discharge for $\beta=1$, p=0.5 Torr.

The radii of striation obey the geometric series law $r_n \approx r_1\beta^n$ (see, Fig. 2). Such dependence was observed in experiments [1] (however, not for argon but for the mixture of N_2 with small addition of acetone).

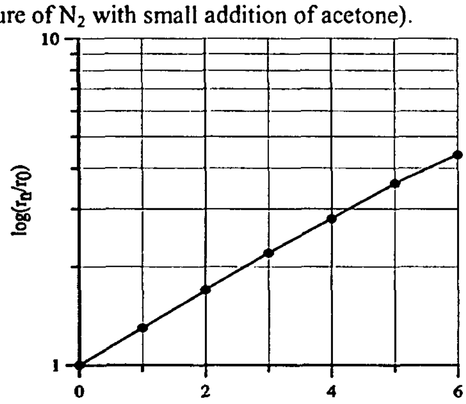

Fig.2. Dependence of striation radii r_n on the number of striation, n, for the case $\beta=1$.

According to the energy balance equation

$$\frac{1}{r^2}\frac{d}{dr}(r^2 j_{\varepsilon r}(r)) = P^f(r) - P^{el}(r) - \sum_k P_k^{in}(r) \qquad (6)$$

the difference between energy gain from the electric field $P^f(r)$ and the energy loss in elastic $P^{el}(r)$ and all inelastic collisions $P^{in}_k(r)$ is compensated for by the spatial divergence of the energy current density, see Fig.3. It is seen that there is a phase shift between the maximum of energy gain in the field and maximum of energy losses in the inelastic collisions, which, in fact, stimulates the propagation of waves (moving striations).

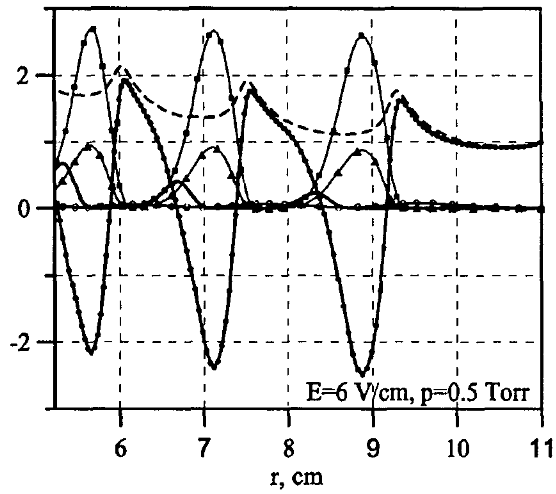

Fig.3. Normalized energy balance terms. ●●●● divergence term, - - - - gain from electric field, ⊖⊖⊖ loss by elastic collisions, ■■■ loss by excitation E_1=11.27 eV, ▲▲▲ loss by excitation E_2=11.7 eV, solid line - loss by ionization E_i=15.7 eV.

4. Conclusions

A spherical glow discharge has been studied in self-consistent kinetic consideration of moving striations.

It is shown that two types of plasma parameters distributions are possible in a stratified spherical discharge: 1) constant averaged field in the spherical discharge gap and electron density $n_e(r) \sim r^{-2}$ with peaks due to striations, and 2) averaged field and electron density are inversely proportional to the distance from the anode. Both regimes were observed in experiments. It is still not clear why real system in PC of spherical glow discharge chooses one of these alternatives.

The presented kinetic model is applied for low-pressure inert gases. For the pressures p>1.5 Torr striation are damped due to energy losses in elastic collisions. In these cases, it is necessary to take into account the excitation of molecule metastable levels and radiative processes.

Special attention should be paid to ionization and recombination processes, which equalize creation and loss of charged particle on the striation length.

5. References

[1] O.A.Nerushev, S.A.Novopashin, V.V.Radchenko, G.I.Sukhinin, *JETF Letters* **66** (1997) 711.

[2] F. Sigeneger, G.I. Sukhinin, R. Winkler, *Plasma Chemistry and Plasma Processing* **20** (2000) 87.

[3] G.I. Sukhinin, A.V. Fedoseev, *ICPIG-2003*.

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